Thomas S. Kuhn

Dubbing and Redubbing: The Vulnerability of Rigid Designation

The issues I shall consider in this paper are central to my current research, and their centrality is a source of present difficulty. In the book on which I am at work, these issues arise only after lengthy prior discussion has led to conclusions I must here present as premises. Limited illustration and evidence for those premises will follow, but only in the later portions of this paper, where they are put to work.

What I am presupposing will be suggested by the following claim: To understand some body of past scientific belief, the historian must acquire a lexicon that here and there differs systematically from the one current in his or her own day. Only by using that older lexicon can historians accurately render certain of the statements that are basic to the science under scrutiny. Those statements are not accessible by means of a translation that uses the current lexicon, not even if it is expanded by the addition of selected terms from its predecessor.

I shall elaborate that claim in the first of the three sections of this paper and illustrate it in the second by an extended analysis of some interrelated terms from the vocabulary of Newtonian mechanics. The final section will apply what I have said to some standard assertions about meaning and/or reference made by proponents of causal theory. Scientific development, I shall then suggest, has from time to time involved sets of scientific terms in systematically interrelated acts of redubbing. Only for the periods between those acts, I shall argue, does dubbing result in rigid designation. That sketch supplies the route on which I now embark.[1]

This paper is a somewhat reduced and considerably revised version of a draft, "Possible Worlds in History of Science," prepared for discussion at a Nobel Symposium held in August 1986. That fuller version, also much revised, has since been published in: Sture Allén, *Possible Worlds in Humanities, Arts, and Sciences* (Berlin: 1988). The abridged form was prepared for the annual Chapel Hill Philosophy Colloquium in October 1986. Both versions, in their published forms, owe much to the cogent criticism and advice of Barbara Partee, as well as to that of my colleagues Ned Block, Sylvain Bromberger, Dick Cartwright, Jim Higginbotham, Paul Horwich, and Judy Thomson.

*

A historian reading an out-of-date scientific text characteristically encounters passages that make no sense. That is an experience I have had repeatedly whether my subject was an Aristotle, a Newton, a Volta, a Bohr, or a Planck.[2] It has been standard to ignore such passages or to dismiss them as the products of error, ignorance, or superstition, and that response is occasionally appropriate. More often, however, sympathetic contemplation of the troublesome passages results in a different diagnosis. The apparent textual anomalies are artifacts, products of misreading.

For lack of an alternative, the historian has been understanding words and phrases in the text as he or she would if they had occurred in contemporary discourse. Through much of the text that way of reading proceeds without difficulty; most terms in the historian's vocabulary are still used as they were by the author of the text. But some sets of interrelated terms are not, and it is failure to isolate those terms and to discover how they were used that has permitted the passages in question to seem anomalous. Apparent anomaly is thus ordinarily evidence of the need for local adjustment of the lexicon, and it often provides clues to the nature of that adjustment as well. An important clue to problems in reading Aristotle's physics is provided by the discovery that the term translated 'motion' in his text refers not simply to change of position but to all changes characterized by two end points. Similar difficulties in reading Planck's early papers begin to dissolve with the discovery that, for Planck before 1907, 'the energy element hv' referred, not to a physically indivisible atom of energy (later to be called 'the energy quantum'), but to a mental subdivision of the energy continuum, any point on which could be physically occupied.

These examples all turn out to involve more than mere changes in the use of terms, thus illustrating what I had in mind years ago when speaking of the "incommensurability" of successive scientific theories.[3] In its original mathematical use 'incommensurability' meant "no common measure," for example of the hypotenuse and side of an isosceles right triangle. Applied to a pair of theories in the same historical line, the term meant that there was no common language into which both could be fully translated.[4] Some statements constitutive of the older theory could not be stated in any language adequate to express its successor and vice versa.

Incommensurability thus equals untranslatability, but what incommensurability bars is not quite the activity of professional translators. Rather, it is a quasi-mechanical activity governed in full by a manual that specifies, as a function of context, which string in one language may, *salva veritate*, be substituted for a given string in the other. Translation of that sort is Quinean, and the point at which I aim will be suggested by the remark that most or all of Quine's arguments for the indeterminacy of translation can with equal force be directed to an opposite conclusion: Instead of there being an infinite number of translations compatible with all normal dispositions to speech behavior, there are often none at all.

With that much, Quine might very nearly agree. His arguments require that a choice be made, but they do not dictate its outcome. In his view, one must either entirely abandon traditional notions of meaning, of intension, or else one must give up the assumption that language is, or could be, universal, that anything expressible in one language, or by using one lexicon, can be expressed also in any other. His own conclusion—that meaning must be abandoned—follows only because he takes universality for granted, and this paper will suggest that there is no sufficient basis for doing so. To possess a lexicon, a structured vocabulary, is to have access to the varied set of worlds which that lexicon can be used to describe. Different lexicons—those of different cultures or different historical periods, for example—give access to different sets of possible worlds, largely but never entirely overlapping. Though a lexicon may be enriched to yield access to worlds previously accessible only with another, the result is peculiar, a point to be elaborated below. In order that the "enriched" lexicon continue to serve some essential functions, the terms added during enrichment must be rigidly segregated and reserved for a special purpose.[5]

What has made the assumption of universal translatability so nearly inescapable is, I believe, its deceptive similarity to a quite different one, in this case an assumption that I share: Anything that can be said in one language can, with sufficient imagination and effort, be *understood* by a speaker of another. What is prerequisite to such understanding, however, is not translation but language learning. Quine's radical translator is, in fact, a language learner. If he succeeds, which I think no principle bars, he will become bilingual. But that does not ensure that he or anyone else will be able to translate from his newly acquired language to the one with which he was raised. Though learnability could in principle imply translatability, the thesis that it does so needs to be argued. Much philosophical discussion instead takes it for granted. Quine's *Word and Object* provides a notably explicit case in point.[6]

I am suggesting, in short, that the problems of translating a scientific text, whether into a foreign tongue or into a later version of the language in which it was written, are far more like those of translating literature than has generally been supposed. In both cases the translator repeatedly encounters sentences that can be rendered in several alternative ways, none of which captures them completely. Difficult decisions must then be made about which aspects of the original it is most important to preserve. Different translators may differ, and the same translator may make different choices in different places, even though the term involved is in neither language ambiguous. Such choices are governed by standards of responsibility, but they are not determined by them. In these matters there is no such thing as being merely right or wrong. The preservation of truth values when translating scientific prose is as delicate a task as the preservation of resonance and emotional tone in the translation of literature. Neither can be fully achieved; even responsible approximation requires the greatest tact and taste. In the scientific case, these generalizations apply, not only to passages that make explicit use of theory, but also and more significantly to those their authors took to be merely descriptive.

Unlike many people who share my generally structuralist leanings, I am not attempting to erase or even to reduce the gap generally thought to separate literal from figurative use of language. On the contrary, I cannot imagine a theory of figurative use—a theory, for example, of metaphor and other tropes—that did not presuppose a theory of literal meanings. Nor, to turn from theory to practice, can I imagine how words could be employed effectively in tropes like metaphor except within a community whose members have previously assimilated their literal use.[7] My point is simply that the literal and the figurative uses of terms are alike in their dependence on preestablished associations between words.

That remark provides entrée to a theory of meaning, but only two aspects of that theory are centrally relevant to the arguments that follow, and I must here restrict myself to them. First, knowing what a word means is knowing how to use it for communication with other members of the language community within which it is current. But that ability does not imply that one knows something that attaches to the word by itself—its meaning, say, or its semantic markers. With occasional exceptions, words do not have meanings individually, but only through their associations with other words within a semantic field. If the use of an individual term changes, then the use of the terms associated with it normally changes as well.

The second aspect of my developing view of meaning is both less standard and more consequential. Two people may use a set of interrelated terms in the same way but employ different sets (in principle, totally disjunct sets) of field coordinates in doing so. Examples will be found in the next section of this paper; meanwhile, the following metaphor may prove suggestive. The United States can be mapped in many different coordinate systems. Individuals with different maps will specify the location of, say, Chicago by means of a different pair of coordinates. But all will nevertheless locate the same city, provided that the maps are scaled to preserve the relative distances between the items mapped. The metric that accompanies each of the various sets of coordinates must, that is, be chosen to preserve the structural geometrical relations within the mapped area.[8]

* *

I have so far dealt in general assertions, omitting both illustration and defense. The argument that begins to supply them will proceed in two stages. The first examines part of the lexicon of Newtonian mechanics, especially the interrelated terms 'force', 'mass', and 'weight'. It asks what one need and need not know to be a member of the community that uses these terms, and indicates how possession of such knowledge constrains what members of the community can express. The second stage examines implications of these constraints for discussions of scientific development, especially for the application to it of causal theory.

The vocabulary in which the phenomena of a field like mechanics are described and explained is itself a historical product, developed over time, and repeatedly transmitted, in its then-current state, from one generation to its successor. In the case of Newtonian mechanics, the required cluster of terms has been stable for some time, and transmission techniques are relatively standard. Examining them will suggest characteristics of what the student acquires in the course of becoming a licensed practitioner of the field.[9]

Before the exposure to Newtonian terminology can usefully begin, other significant portions of the lexicon must be in place. Students must, for example, already have a vocabulary adequate to refer to physical objects and to their locations in space and time. Onto this they must have grafted a mathematical vocabulary rich enough to permit the quantitative description of trajectories and the analysis of velocities and accelerations of bodies moving along them.[10] Also, at least implicitly, they must command a notion of extensive magnitude, a quantity whose value for the whole of a body is the sum of its values for the body's parts. Quantity of matter provides a standard example. These terms can all be acquired without resort to Newtonian theory, and the student must control them before that theory can be learned. The other lexical items required by that theory—most notably 'force', 'mass', and 'weight' in their Newtonian senses—can only be acquired together with the theory itself.

Five aspects of the way in which these Newtonian terms are learned require particular illustration and emphasis. First, as already indicated, learning cannot begin until a considerable antecedent vocabulary is in place. Second, in the process through which the new terms are acquired, definition plays a negligible role. Rather than being defined, these terms are introduced by exposure to examples of their use, examples provided by someone who already belongs to the speech community in which they are current. That exposure often includes actual exhibits, for example in the student laboratory, of one or more exemplary situations to which the terms in question are applied by someone who already knows how to use them. The exhibits need not be actual, however. The exemplary situations may instead be introduced by a description conducted primarily in terms drawn from the antecedentally available vocabulary, but in which the terms to be learned also appear here and there. The two processes are for the most part interchangeable, and most students encounter them both, in some mix or other. Both include an indispensable ostensive or stipulative element: terms are taught through the exhibit, direct or by description, of situations to which they apply.[11] The learning that results from such a process is not, however, about words alone but equally about the world in which they function. When I use the phrase 'stipulative descriptions' in what follows, the stipulations I have in mind will be simultaneously and inseparably about both the substance and the vocabulary of science, about both the world and the language.

A third significant aspect of the learning process is that exposure to a single exemplary situation seldom or never supplies enough information to permit the student to use a new term. Several examples of varied sorts are required, often accompanied by examples of apparently similar situations to which the term in question does not apply. The terms to be learned, furthermore, are seldom applied to these situations in isolation, but are instead embedded in whole sentences or statements, among which are some usually referred to as laws of nature.

Fourth, among the statements involved in learning one previously unknown term are some that include other new terms as well, terms that must be acquired together with the first. The learning process thus interrelates a set of new terms, giving structure to the lexicon that contains them. Finally, though there is usually considerable overlap between the situations to which individual language learners are exposed (and even more between the accompanying statements), individuals can in principle communicate fully even though they acquired the terms with which they do so along very different routes. To the extent that the process I am describing supplies individuals with anything resembling a definition, it is not a definition that need be shared by other members of the speech community.

For illustrations, consider first the term 'force'. The situations that exemplify a force's presence are of varied sorts. They include, for example, muscular exertion, a stretched string or spring, a body possessed of weight (note the occurrence of another of the terms to be learned), or, finally, certain sorts of motion. The last is particularly important and presents particular difficulties to the student. As Newtonians use 'force', not all motions signify the presence of its referent, and examples that display the distinction between forced and force-free motions are therefore required. Their assimilation, furthermore, demands the suppression of a highly developed pre-Newtonian intuition. For children and Aristotelians, the standard example of a forced motion is the hurled projectile. Force-free motion is for them exemplified by the falling stone, the spinning top, or the rotating flywheel. For the Newtonian, all of these are cases of forced motion. The only example of a Newtonian force-free motion is motion in a straight line at constant speed, and that can be exhibited directly only in interplanetary space. Teachers nevertheless try. (I still remember the contrived lecture-demonstration – a block of ice sliding on a sheet of glass – that helped me undo prior intuitions and acquire the Newtonian concept of 'force'.) But for most students the main path to this key aspect of the use of the term is provided by Newton's first law of motion: In the absence of an external force applied to it, a body moves continuously at constant speed in a straight line. It exhibits, by description, the motions that require no force.[12]

More will need to be said about 'force', but let me first look briefly at its two

Newtonian companions, 'weight' and 'mass'. The first refers to a particular sort of force, the one that causes a physical body to press on its supports while at rest or to fall when unsupported. In this still-qualitative form the term 'weight' is available prior to Newtonian 'force' and is used during the latter's acquisition. 'Mass' is usually introduced as equivalent to 'quantity of matter', where matter is the substrate underlying physical bodies, the stuff of which quantity is conserved as the qualities of material bodies change. Any feature that, like weight, picks out a physical body, is an index also of the presence of matter and of mass. As in the case of 'weight' and unlike the case of 'force', the qualitative features by which one picks out the referents of 'mass' are identical with those of pre-Newtonian usage.

But the Newtonian use of all three terms is quantitative, and the Newtonian form of quantification alters both their individual uses and the interrelationships between them.[13] Only the unit measures may be established by convention; the scales must be chosen so that weight and mass are extensive quantities and so that forces can be added vectorially. (Contrast the case of temperature, in which both unit and scale can be chosen by convention.) Once again, the learning process requires the juxtaposition of statements involving the terms to be learned with situations drawn directly or indirectly from nature.

Begin with the quantification of 'force'. Students acquire the full quantitative concept by learning to measure forces with a spring balance or some other elastic device. Such instruments had appeared nowhere in scientific theory or practice before Newton's time, when they took over the conceptual role previously played by the pan balance. But they have since been central, for reasons that are conceptual rather than pragmatic. The use of a spring balance to exhibit the proper measure of force requires, however, recourse to two statements ordinarily described as laws of nature. One of these is Newton's third law, which states, for example, that the force exerted by a weight on a spring is equal and opposite to the force exerted by the spring on the weight. The other is Hooke's law, which states that the force exerted by a stretched spring is proportional to the spring's displacement. Like Newton's first law, these are first encountered during language learning, where they are juxtaposed with examples of situations to which they apply. Such juxtapositions play a double role, simultaneously stipulating how the word 'force' is to be used and how the world populated by forces behaves.

Turn now to the quantification of the terms 'mass' and 'weight'. It illustrates with special clarity a key aspect of the lexical acquisition process, one that has not yet been considered. To this point, my discussion of Newtonian terminology has probably suggested that, once the required antecedent vocabulary is in place, students learn the terms that remain by exposure to some single specifiable set of examples of their use. Those particular examples may well have seemed to provide necessary conditions for the acquisition of those terms. In practice, however, cases of that sort are very rare. Usually there are alternate sets of examples that will serve for the acquisition of the same term or terms. And, though it usually makes no difference to which set of these examples an individual has, in fact, been exposed, there are special circumstances in which the differences between sets prove very important.

In the case of 'mass' and 'weight', one of these alternate sets is standard. It is able to supply the missing elements of both vocabulary and theory together, and it probably therefore enters the lexical acquisition process for all students. But logically other examples would have done as well, and for most students some of them also play a role. Begin with the standard route, which first quantifies 'mass' in the guise of what today is called 'inertial mass'. Students are presented with Newton's second law – force equals mass times acceleration – as a description of the way moving bodies actually behave; but the description makes essential use of the still incompletely established term 'mass'. That term and the second law are thus acquired together, and the law can thereafter be used to supply the missing measure: the mass of a body is proportional to its acceleration under the influence of a known force. For purposes of concept acquisition, centripetal-force apparatus provides a particularly effective way to make the measurement.

Once mass and the second law have been added to the Newtonian lexicon in this way, the law of gravity can be introduced as an empirical regularity. Newtonian theory is applied to observation of the heavens and the attractions manifest there are compared to those between the Earth and bodies resting on it. The mutual attraction between bodies is thus shown to be proportional to the product of their masses, an empirical regularity that can be used to introduce the still missing aspects of the Newtonian term 'weight'. 'Weight' is now seen to denote a relational property, one that depends on the presence of two or more bodies. It can therefore, unlike mass, differ from one location to another, at the surface of the Earth and of the Moon, for example. That difference is captured only by the spring balance, not by the previously standard pan balance, which yields the same reading at all locations. What the pan balance measures is mass, a quantity that depends only on the body and on the choice of a unit measure.

Because it establishes both the second law and the use of 'mass', the sequence just sketched provides the most direct route to many applications of Newtonian theory.[14] That is why it plays so central a role in introducing the theory's vocabulary. But it is not, as previously indicated, required for that purpose, and, in any case, it rarely functions alone. Let me now consider a second route along which the use of 'mass' and 'weight' can be established. It starts from the same point as the first, by quantifying the notion of force with the aid of a spring balance. Next, 'mass' is introduced in the guise of what is today labeled 'gravitational mass'. A stipulative description of the way the world is provides students with the notion of gravity as a universal force of attraction between pairs of material bodies, its magnitude proportional to the mass of each. With the missing aspects of 'mass' thus supplied, weight can be explained as a relational property, the force resulting from gravitational attraction.

That is a second way to establish the use of the Newtonian terms 'mass' and 'weight'. With them in hand Newton's second law, the still missing component of Newtonian theory, can be introduced as empirical, a consequence simply of observation. For that purpose, centripetal force apparatus is again appropriate, no longer to measure mass, as it did on the first route, but now rather to determine the relation between applied force and the acceleration of a mass previously measured by gravitational means. The two routes thus differ in what must be stipulated about nature in order to learn Newtonian terms, what can be left instead for empirical discovery. On the first route, the second law enters stipulatively, the law of gravitation empirically. On the second, their epistemic status is reversed. In each case one, but only one, of the laws is, so to speak, built into the lexicon. I do not quite want to call such laws analytic, for experience with nature was essential to their initial formulation. Yet they do have something of the necessity that the label 'analytic' implies. Perhaps 'synthetic a priori' comes closer.

There are, of course, still other ways in which the quantitative elements of 'mass' and 'weight' can be acquired. For example, Hooke's law having been introduced together with 'force', the spring balance can be stipulated as the measure of weight, and mass can be measured, again by stipulation, in terms of the vibration period of a weight at the end of a spring. In practice, several of these applications of Newtonian theory usually enter into the process of acquiring Newtonian language, information about the lexicon, and information about the world being distributed in an indivisible mix among them. Under those circumstances, one or another of the examples introduced during lexical acquisition can, when occasion requires, be adjusted or replaced in the light of new observations. Other examples will maintain the lexicon stable, keeping in place a set of quasi necessities equivalent to those initially induced by language learning.

Clearly, however, only a certain number of examples may be altered piecemeal in this way. If too many require adjustment, then it is no longer individual laws or generalizations that are at stake, but the very vocabulary in which they are stated. A threat to that vocabulary is, however, a threat also to the theory or laws essential to its acquisition and use. Could Newtonian mechanics withstand revision of the second law, of the third law, of Hooke's law, or the law of gravity? Could it withstand the revision of any two of these, of three, or of all four? These are not questions that individually have yes or no answers. Rather, like Wittgenstein's "Could one play chess without the queen?", they suggest the strains placed on a lexicon confronted by questions that its designer, whether God or cognitive evolution, did not anticipate its being required to answer.[15] What should one have said when confronted by an egg-laying creature that suckles its young? Is it a mammal or is it not? These are the circumstances in which, as Austin put it, "*We don't know what to say.* Words literally fail us."[16] Such circumstances, if they endure for long, call forth a locally different lexicon, one that permits an answer, but to a slightly altered question: "Yes, the creature is a mammal" (but to be a mammal is not what it was before). The new lexicon opens new possibilities, ones that could not have been stipulated by the use of the old.

To clarify what I have in mind, let me suppose that there are only two ways in which use of the terms 'mass' and 'weight' can be acquired: one that stipulates the second law and finds the law of gravity empirically; another that stipulates the law of gravity and discovers the second law empirically. Suppose further that the two routes are exclusive; students traverse one or the other so that the necessities of the lexicon and the contingencies of experiment are kept separate on each. Clearly, these two routes are very different, but the differences will not ordinarily interfere with full communication among those who use the terms. All will pick out the same objects and situations as the referents of the terms they share, and all will agree about the laws and other generalizations governing these objects and situations. All are thus fully participants in a single speech community. What individual speakers may differ about is the epistemic status of generalizations that community members share, and such differences are not usually important. Indeed, in *ordinary* scientific discourse, they do not emerge at all. While the world behaves in anticipated ways—the ones for which the lexicon evolved—these differences between individual speakers are of little or no consequence.

But change of circumstance may make such differences consequential. Imagine that a discrepancy is discovered between Newtonian theory and observation, for example celestial observations of the motion of the lunar perigee. Scientists who had learned Newtonian 'mass' and 'weight' along the first of my two lexical-acquisition routes would be free to consider altering the law of gravity as a way to remove the anomaly. On the other hand, they would be bound by language to preserve the second law. On the other hand, scientists who had acquired 'mass' and 'weight' along my second route would be free to suggest altering the second law but would be bound by language to preserve the law of gravity. A difference in the language-learning route, one that had had no effect while the world behaved as anticipated, would become the source of a difference of opinion when anomalies were found.

Now suppose that neither the revisions that preserved the second law nor those that preserved the law of gravity proved effective in eliminating anomaly. The next step would be an attempt at revisions that altered both laws together, and those revisions the lexicon will not, in its present form, permit.[17] Such attempts are often successful nonetheless, but they require recourse to such devices as metaphorical extension, devices that alter the meanings of lexical items themselves. After such revision, say the transition to an Einsteinian vocabulary, one can write down strings of symbols that *look like* revised versions of the second law and the law of gravity. But the resemblance is deceptive, because some symbols in the new strings attach to nature differently from the corresponding symbols in the old, thus distinguishing between situations which, in the antecedently available vocabulary, were the same.[18] They are the symbols for terms whose acquisition involved laws that have changed form with the change of theory: the differences between the old laws and the new are reflected by the terms acquired with them. Each of the resulting lexicons then gives access to its own set of possible worlds, and the two sets are disjoint. Translations involving terms introduced with the altered laws are impossible.

The impossibility of translation does not, of course, bar users of one lexicon from learning the other. And having done so, they can join the two together, enriching their initial lexicon by adding to it sets of terms from the new one they have acquired. That is, as I have argued elsewhere, what historians do both for themselves and for their readers.[19] But the sense of enrichment involved is peculiar. It is like the enrichment that gives philosophers an alternative set of terms for describing emeralds: not 'blue', 'green', and the traditional roster of color terms, but 'grue', 'bleen', and the names of the other occupants of the corresponding spectrum.[20] One set of terms is projectible, supports induction, the other not. One set of terms is available for descriptions of the world, the other is reserved for the special purposes of the philosopher, the historian, the writer of certain sorts of fiction. However useful these lexical add-ons may be, the integrity of language requires that they be segregated, reserved for distinct sorts of discourse. If communication is to succeed, then all participants in discourse must know at all times which set of terms is being used.

Students of literature have long taken for granted that metaphor and its companion devices (those that alter the interrelations among words) provide entrée to new worlds and make translation impossible by doing so. Similar characteristics have been widely attributed to the language of political life and, by some, to the entire range of the human sciences. But the natural sciences, dealing objectively with the real world (as they do), are generally held to be immune. Their truths (and falsities) are thought to transcend the ravages of temporal, cultural, and linguistic change. I am suggesting, of course, that they cannot do so. Neither the descriptive nor the theoretical language of a natural science provides the bedrock such transcendence would require. I shall not in this paper even attempt to deal with the philosophical problems consequent upon that point of view.[21] Rather, I shall attempt to reinforce them by examining a technique that claims to set them aside.

* * *

Change of lexicon, I have been arguing, can change the meaning of some group or groups of interrelated terms. Problems about the possibility of truth-preserving translations result, and efforts to avoid them have in recent years taken a characteristic form. Truth values, these efforts emphasize, depend only on reference, not on meaning or mode of use. Discussions of truth value need not, therefore, invoke meaning at all, at least not in a sense so nearly traditional as the one I appear to have invoked here.[22]

Among such efforts, the most influential is the causal theory of reference, and many of the advances achieved with its aid are likely to prove permanent. But causal theory, which invokes an original act of baptism or dubbing as an essential determinant of reference, is intrinsically historical, and its expositors resort repeatedly to putative examples from scientific development. These examples, I believe, quite regularly fail in ways that are both consequential and illuminating. To see what is involved, I conclude this paper by examining two well-known examples developed by Hilary Putnam, the philosopher who has most explicitly applied causal theory to history.[23]

Excluding proper names, I doubt that there is any set of terms for which causal theory works precisely; but it comes very close to doing so for terms like 'gold', and the plausibility of its application to natural-kind terms depends on the existence of such cases. Terms that behave like 'gold' ordinarily refer to naturally occurring, widely distributed, functionally significant, and easily recognized substances. Such terms occur in the languages of most or all cultures, retain their original use over time, and refer throughout to the same sorts of samples. There is little problem about translating them, for they occupy closely equivalent positions in all lexicons. 'Gold' is among the closest approximations we have to an item in a neutral, mind-independent observation vocabulary.

When a term is of this sort, modern science can often be used not only to specify the common essence of its referents but actually to single them out. Modern theory, for example, identifies gold as the substance with atomic number 79, and licenses specialists to identify it by the application of such techniques as x-ray spectroscopy. Neither the theory nor the instrument was available seventy-five years ago, but it is nevertheless reasonable to suggest, as Putnam does, that the referents of 'gold' are and have always been the same as the referents of 'substance with atomic number 79'. Exceptions to that equation are few, and they result primarily from the ever-increasing refinement of our ability to detect impurities and forgeries. For the causal theorist, therefore, 'having atomic number 79', is *the* essential property of gold – the single property such that, if gold in fact does have it, then it has it necessarily. Other properties – yellowness and ductility, for example – are superficial and correspondingly contingent. Kripke suggests that gold might even be blue, its apparent yellowness resulting from an optical illusion.[24] Though individuals may, in fact, use color and other superficial characteristics when picking out samples of gold, that practice tells nothing essential about the referents of the term.

'Gold' presents a relatively special case, however, and what is special about it obscures essential limitations on the conclusions it will support. More representative is Putnam's most developed example, 'water', and the problems that arise with it are still more severe in the case of such other widely discussed terms as 'heat' and 'electricity'.[25] For water the discussion divides in two parts. In the first, which is the more familiar, Putnam imagines a possible world containing Twin Earth, a planet just like our own except that the stuff called 'water' by Twin Earthians is not H_2O but a different liquid with a very long and complicated chemical formula abbreviated XYZ. "Indistinguishable from water at normal temperature and pressure," XYZ is the stuff that on Twin Earth quenches thirst, rains from the skies, and fills oceans and lakes, much as water does here. If a spaceship from Earth ever visits Twin Earth, Putnam writes:

> then, the supposition at first will be that 'water' has the same meaning on Earth and Twin Earth. This supposition will be corrected when it is discovered that 'water' on Twin Earth is XYZ, and the Earthian spaceship will report somewhat as follows: "On Twin Earth the word 'water' means XYZ." (See n. 23.)

As in the case of gold, superficial qualities like quenching thirst or raining from the skies have no role in determining to what substance the term 'water' properly refers.

Two aspects of Putnam's fable require special notice. First, the fact that Twin Earthians call XYZ by the name 'water' (the same symbol that Earthians use for the stuff that lies in lakes, quenches thirst, etc.) is an irrelevancy. The difficulties presented by this story will emerge more clearly if the visitors from Earth use their own language throughout. Second, and presently central, whatever the visitors call the stuff that lies in Twin Earthian lakes, the report they send home should not be about language but about chemistry. It must take some form like: "Back to the drawing board! Something is badly wrong with chemical theory."

The terms 'XYZ' and 'H_2O' are drawn from modern chemical theory, and that theory is incompatible with the existence of a substance with properties very nearly the same as water but described by an elaborate chemical formula. Such a substance would, among other things, be too heavy to evaporate at normal terrestrial temperatures. Its discovery would present the same problems as the simultaneous violation of Newton's second law and the law of gravity described in the last section. It would, that is, demonstrate the presence of fundamental errors in the chemical theory that gives meanings to compound names like 'H_2O' and the unabbreviated form of 'XYZ'. Within the lexicon of modern chemistry, a world containing both our Earth and Putnam's Twin Earth is lexically possible, but the composite statement that describes it is necessarily false. Only with a differently structured lexicon, one shaped to describe a very different sort of world, could one, without contradiction, describe the behavior of 'XYZ' at all, and in that lexicon 'H_2O' might no longer refer to what we call 'water'.

So much for the first part of Putnam's argument. In the second he applies it more concretely to the referential history of 'water', suggesting that "we roll the time back to 1750," and continuing:

> At that time chemistry was not developed on either Earth or Twin Earth. The typical Earthian speaker of English did not know water consisted of hydrogen and oxygen, and the typical Twin Earthian speaker of English did not know 'water' consisted of XYZ. . . . Yet the extension of the term 'water' was just as much H_2O on Earth in 1750 as in 1950; and the extension of the term 'water' was just as much XYZ on Twin Earth in 1750 as in 1950. (See n. 23.)

In journeys through time, as in those through space, Putnam suggests, it is chemical formula, not superficial qualities, that determines whether a given substance is water.

For present purposes, attention can be restricted to Earthian history, and on Earth Putnam's argument for 'water' is the same as it was for 'gold'. The extension of 'water' is determined by the original sample together with the relation sameness-of-kind. That sample dates from before 1750, and the nature of its members has been stable. So has the relation sameness-of-kind, though *explanations* of what it is for two bodies to be of the same kind have varied widely. What matters, however, is not explanations but what gets picked out, and identifying samples of H_2O is, according to causal theory, the best means yet found to pick out samples of the same kind as the original set. Give-or-take a few discrepancies at the margins, discrepancies due to refinement of technique or perhaps to change of interest, 'H_2O' refers to the same samples that 'water' referred to in either 1750 or 1950. Apparently causal theory has rendered the referents of 'water' immune to changes in the concept of water, the theory of water, and the way samples of water are picked out. The parallel between causal theory's treatment of 'gold' and of 'water' seems complete.

But in the case of water, difficulties arise. 'H_2O' picks out samples not only of water but also of ice and steam. H_2O can exist in all three states of aggregation—solid, liquid, and gaseous—and it is therefore not the same as water, at least not as picked out by the term 'water' in 1750. The difference in items referred to is, furthermore, by no means marginal, like that due to impurities for example. Whole categories of substance are involved, and their involvement is by no means accidental. In 1750 the primary differences between the species recognized by chemists were still more or less those between what are now called the states of aggregation. Water, in particular, was an elementary body of which liquidity was an essential property. For some chemists the term 'water' referred to the generic liquid, and it had done so for many more only a few generations before. Not until the 1780s, in an episode long known as the "Chemical Revolution," was the taxonomy of chemistry transformed so that a chemical species might exist in all three states of aggregation. Thereafter, the distinction between solids, liquids, and gases became physical, not chemical. The discovery that *liquid* water was a compound of two *gaseous* substances, hydrogen and oxygen, was an integral part of that larger transformation and could not have been made without it.

This is not to suggest that modern science is incapable of picking out the stuff that people in 1750 (and most people still) label 'water'. That term refers to *liquid* H_2O. It should be described not simply as H_2O but as close-packed H_2O particles in rapid relative motion. Marginal differences again aside, samples answering that compound description are the ones picked out in 1750 and before by the term 'water'. But this modern description leads to a new network of difficulties, difficulties that may ultimately threaten the concept of natural kinds and that meanwhile must bar the automatic application of causal theory to them.

Causal theory was initially developed with notable success for application to proper names. Its transfer from them to natural-kind terms was facilitated—perhaps made possible—by the fact that natural kinds, like single individual creatures, are denoted by short and apparently arbitrary names, names coextensive with those of the corresponding kind's single essential property. Our examples have been 'gold' paired with 'having atomic number 79', and 'water' paired with 'being H_2O'. The latter member of each pair names a property, of course, as the name coupled with it does not. But so long as only a single essential property is required by each natural kind that difference is inconsequential. When two non-coextensive names are required, however—'H_2O' and 'liquidity' in the case of water—then each name, if used alone, picks out a larger class than the pair does when conjoined, and the fact that they name properties becomes central. For if two properties are required, why not three or four? Are we not back to the standard set of problems that casual theory was intended to resolve: which properties are essential, which accidental; which properties belong to a kind by definition, which are only contingent? Has the transition to a developed scientific vocabulary really helped at all?

I think it has not. The lexicon required to label attributes like being-H_2O or being-close-packed-particles-in-rapid-relative-motion is rich and systematic. No one can use any of the terms that it contains without being able to use a great many. And given that vocabulary, the problems of choosing essential properties arise again, except that the properties involved can no longer be dismissed as superficial. Is deuterium hydrogen, for example, and is heavy water really water? And what may one say about a sample of close-packed particles of H_2O in rapid relative motion at the critical point—under the conditions of temperature and pressure, that is, at which the liquid, solid, and gaseous states are indistinguishable? Is it really water? The use of theoretical rather than superficial properties offers great advantages, of course. There are fewer of the former; the relations between them are more systematic; and they permit both richer and more precise discriminations. But they come no closer to being essential or necessary properties than the superficial ones they appear to supplant.

The inverse argument proves even more significant. The so-called superficial properties are no less necessary than their apparently essential successors. To say that water is liquid H_2O is to locate it within an elaborate lexical and theoretical system. Given that system, as one must be in order to use the label, one can in principle predict the superficial properties of water (just as one could those of XYZ), compute its boiling and freezing points, the optical wavelengths that it will transmit, and so on.[26] If water is liquid H_2O, then these properties are necessary to it. If they were not realized in practice, that would be a reason to doubt that water really was H_2O.

This last argument applies also to the case of gold, in which causal theory apparently succeeded. 'Atomic number' is a term from the lexicon of atomic-molecular theory. Like 'force' and 'mass', it must be learned together with other terms deployed in that theory, and the theory itself must play a role in the acquisition process. When the process is complete, one can replace the label 'gold' with 'atomic number 79', but one can then also replace the label 'hydrogen' with 'atomic number 1', 'oxygen' with 'atomic number 8', and so on to a total well over a hundred. And one can do something more important as well. Invoking such other theoretical properties as electronic charge and mass, one can in principle, and to a considerable extent in fact, predict the superficial qualities—density, color, ductility, conductivity, and so on—that samples of the corresponding substance will possess at normal temperatures. Those properties are no more accidental than having-atomic-number-79. That color is a superficial property does not make it a contingent one. Furthermore, in a comparison of superficial and theoretical qualities, the former have a double priority. If the theory that posits the relevant theoretical properties could not predict these superficial qualities or some of them, there would be no reason to take it seriously. If gold were blue for a normal observer under normal conditions of illumination, its atomic number would not be 79. In addition, superficial properties are the ones called upon in those difficult cases of discrimination characteristically raised by new theories. Is deuterium really hydrogen, for example? Are viruses alive?[27]

What remains special about 'gold' is simply that, unlike 'water', only one of the underlying properties recognized by modern science—having atomic number 79—need be called upon to pick out members of the sample to which the term has continued through history to refer.[28] 'Gold' is not the only term that possesses or closely approximates this characteristic. So do many of the basic-level referring terms used in everyday speech, including the everyday use of the term 'water'. But not all everyday terms are of this sort. 'Planet' and 'star' now categorize the world of celestial objects differently from the way they did before Copernicus, and the differences are not well described by phrases like "marginal adjustment" or "zeroing in." Similar transitions have characterized the historical development of virtually all the referring terms of the sciences, including the most elementary: 'force', 'species', 'heat', 'element', 'temperature', and so on. It is terms like these that have provided this paper's primary concern, and a three-item summary of what it has had to say about them can now bring it quickly to a close.

Dealing with such Newtonian terms as 'mass', 'force', and 'weight', the second section of this paper emphasized that they are learned in use. The student first encounters them in authoritative statements about the world by someone who already knows how to use them and who illustrates their correct use by juxtaposing statements that contain them with exemplary situations to which those statements do or do not apply. Two parallels to that position are implicit in the third section's discussion of causal theory. First, the role played by actual examples in anchoring terms of the lexicon to the world recurs in causal theory's emphasis on an original act of dubbing, which supplies examples canonical for later use. Second, the emphasis on language learning—on the way the lexicon is transmitted from one generation to the next—is duplicated in causal theory's emphasis upon the chain linking later users of a term to the canonical sample. These are important parallels, especially because their recognition makes it possible to isolate the key respect in which the position taken in this paper diverges from that of causal theory. Dubbing is here seen as a process that recurs again and again through history. The putative "original sample" may mark the beginning of the chain, if any beginning is needed, but there is nothing privileged about its membership. The sets of canonical examples used in transmitting the lexicon change in the course of time, and not all the changes can properly be viewed as mere adjustments.

Many of them, of course, are small adjustments, for example those due to refinements in the process of purifying gold. But others are both systematic and wide reaching. Changes in the sample required to transmit a term like 'force' cannot be made in isolation, but require simultaneous changes in the samples used to introduce such terms as 'mass' and 'weight'. Moving circular motions from the category of force-free to that of forced motions required shifting uniform linear motions from forced to force-free. Simultaneously, the exhibit of a new instrument, the spring balance, was required to introduce the Newtonian term 'force', and examples that introduced the corresponding term 'weight' were required to exhibit not simply the body whose weight was in question, but one or more other bodies in gravitational interaction with it. Similarly, the development of the chemical lexicon in which H_2O is embedded required an almost total readjustment in the samples used to introduce the basic chemical kinds. No workable form of chemistry could have survived the change that placed liquid water in the same category as ice and steam but continued elsewhere to regard the divisions between states of aggregation as chemically fundamental. In short, dubbing and the procedures that accompany it ordinarily do more than place the dubbed object together with other members of its kind. They also locate it with respect to other kinds, placing it not simply within a taxonomic category but within a taxonomic system. Only while that system endures do the names of the kinds it categorizes designate rigidly.

A lexicon that embodies such interrelationships between terms necessarily also embodies knowledge of the world those terms can be used to describe, and that knowledge may be placed at risk. As time goes on and new demands are placed on the lexicon, conditions may be encountered that defy description. The Newtonian lexicon could not, without internal contradiction, describe a world in which both Newton's second law and the law of gravity were violated. Prior to the eighteenth century, the lexicon of chemistry could not provide a coherent description of a world in which a sample of liquid could change its state of aggregation without simultaneously changing its chemical kind. But these changes, both in mechanics and in chemistry, nevertheless came about, together with the change of lexicon they required. And the new lexicon, once consolidated, displayed the same sorts of limitations as its predecessor. It could not, that is, be used to to provide coherent descriptions of some aspects of the world described by its predecessor. Here and there the old and new lexicons embodied differently structured, nonhomologous taxonomies, and statements involving terms from the regions where the two differed were not translatable between them.

Those untranslatable statements are the ones from which this paper began, the ones that make no sense to the historian who encounters them in an out-of-date text, and which lead him or her to abandon translation in favor of language learning. Returning to them closes a circle. Though well aware that challenging problems are located within it, I shall not start another lap here and now.

Notes

1. Throughout this paper I shall continue to speak of the lexicon, of terms, and of statements. My concern, however, is actually with conceptual or intensional categories more generally, e.g., with those that may reasonably be attributed to animals or to the perceptual system.

2. For Newton, see my "Newton's '31st Query' and the Degradation of Gold," *Isis* 42 (1951), 296–98. For Bohr, see John L. Heilbron and Thomas S. Kuhn, "The Genesis of the Bohr Atom," *Historical Studies in the Physical Sciences*, 1 (1969), 211–90, where the nonsense passages that gave rise to the project are quoted on p. 271. For an introduction to the other examples mentioned, see my "What are Scientific Revolutions?" in L. J. Daston, M. Heidelberger, and L. Kruger, eds., *The Probabilistic Revolution*, vol. 1, *Ideas in History* (Cambridge: MIT Press, 1987), 7–22.

3. For a fuller and more nuanced discussion of this point and those that follow see my "Commensurability, Comparability, Communicability," in P. D. Asquith and T. Nickles, eds., *PSA 1982*, vol. 2 (East Lansing: Philosophy of Science Association, 1983), 669–88.

4. My original discussion described nonlinguistic as well as linguistic forms of incommensurability. That I now take to have been an overextension resulting from my failure to recognize how large a part of the apparently nonlinguistic component was acquired with language during the learning process. The acquisition during language learning of what I once took to be incommensurability with respect to instrumentation is, for example, illustrated by the discussion of the spring balance in the next section of this paper.

5. To speak of different lexicons as giving access to different sets of possible worlds is not simply to add one more kind of accessibility relation to those that currently generate different kinds of modal

necessity. There is no type of necessity corresponding to lexical accessibility. Excepting purely analytic statements or combinations of statements, for which see below, no statement framable in a given lexicon is necessary simply because it can be accessed in that lexicon. More generally, lexical accessibility seems to cut across the standard set of accessibility relations. Perhaps all possible-world analyses of modalities and semantics should be relativized to the lexicons with which the appropriate set of possible worlds might have been stipulated or described.

6. W. V. O. Quine, *Word and Object* (New York: John Wiley & Sons; Cambridge: MIT Press; 1960), 47, 70f.

7. See my "Metaphor in Science," in Andrew Ortony, ed., *Metaphor and Thought* (Cambridge: Cambridge University Press, 1979), 409–19.

8. Some preliminary indications of what these cryptic remarks intend are supplied in my "Commensurability, Comparability, Communicability" (See note 3 above).

9. I discuss the *transmission* of a lexicon because it is a source of clues to what the individual's possession of a lexicon entails. Nothing, however, depends upon the lexicon's being acquired by transmission. The consequences would be the same if, for example, it were a consequence of genetics or else implanted by a skilled neurosurgeon. I shall, for example, shortly emphasize that transmitting a lexicon requires repeated recourse to concrete examples. Implanting the same lexicon surgically would, I am suggesting, have involved implanting the memory traces left by exposure to such examples.

10. In practice, the techniques for describing velocities and accelerations along trajectories are usually learned in the same courses that introduce the terms to which I turn next. But the first set can be acquired without the second, whereas the second cannot be acquired without the first.

11. The terms "ostension" and "ostensive" have two different uses, which for present purposes need to be distinguished. In one, these terms imply that *nothing but* the exhibit of a word's referent is needed to learn or to define it. In the other, they imply only that *some* exhibit is required during the acquisition process. I shall, of course, be using the second sense of the terms. The propriety of extending them to cases in which description in an antecedent vocabulary replaces an actual exhibit depends on recognizing that description does not supply a string of words equivalent to the statements containing the words to be learned. Rather it enables students to visualize the situation and apply to the visualization the same mental processes (whatever they may be) that would otherwise have been applied to the situation as perceived.

12. Newton's first law is a logical consequence of his second, and Newton's reason for stating them separately has long been a puzzle. The answer may well lie in pedagogic strategy. If Newton had permitted the second law to subsume the first, his readers would have had to sort out his use of 'force' and of 'mass' together, an intrinsically difficult task further complicated by the fact that the terms had previously been different not only in their individual use but in their interrelation. Separating them to the extent possible displayed the nature of the required changes more clearly.

13. Though my analysis diverges from theirs, many of the considerations that follow (as well as a few of those introduced above) were suggested by contemplation of the techniques developed by J. D. Sneed and Wolfgang Stegmüller for formalizing physical theories, especially by their manner of introducing theoretical terms. Note also that these remarks suggest a route to the solution of a central problem of their approach, how to distinguish the core of a theory from its expansions. For this problem see my paper, "Theory Change as Structure Change: Comments on the Sneed Formalism," *Erkenntnis*, 10 (1976), 179–99.

14. All applications of Newtonian theory depend on understanding 'mass', but for many of them 'weight' is dispensable.

15. Twenty-five years ago the quotation was a standard part of what I now discover was a merely oral tradition. Though clearly "Wittgensteinian," it is not to be found in any of Wittgenstein's published writings. I preserve it here because of its recurrent role in my own philosophical development

and because I've found no published substitute that so clearly prohibits the response that the question might be answerable if only there were more information.

16. J. L. Austin, "Other Minds," in *Collected Philosophical Papers* (Oxford: Oxford University Press, 1961), 44–84. The quoted passage occurs on p. 56, and the italics are Austin's. For examples from literature of situations in which words fail us, see James Boyd White, *When Words Lose their Meaning*, (Chicago: University of Chicago Press, 1984). I have compared an example from the sciences witih one from developmental psychology in "A Function for Thought Experiments," reprinted in *The Essential Tension* (Chicago: University of Chicago Press, 1977), 240–65.

17. At this point I will seem to be reintroducing the previously banished notion of analyticity, and perhaps I am. Using the Newtonian lexicon, the statement "Newton's second law and the law of gravity are both false" is itself false. Furthermore, it is false by virtue of the meanings of the Newtonian terms 'force' and 'mass'. But it is not—unlike the statement "Some bachelors are married"—false by virtue of the *definitions* of those terms. The meanings of 'force' and 'mass' are not embodiable in definitions, but rather in their relation to the world. The necessity to which I here appeal is not so much analytic as synthetic a priori.

18. In fact, for the Newton-to-Einstein transition, the most significant lexical change is in the antecedent kinematic vocabulary for space and time, and it moves from there upward into the vocabulary of mechanics.

19. See the reference cited in note 3.

20. Like the Newtonian terms I have been examining, the terms in any color vocabulary form an interrelated set. One cannot alter one of them without making corresponding alterations in a number of the others as well. Note, however, that the parallel I am drawing is incomplete. Because their differences do not affect the structure of the color vocabulary itself, one can translate between the projectable 'blue'/'green' vocabulary and the unprojectable vocabulary containing 'bleen'/'grue'.

21. Despite my critics, I do not think that the position developed here leads to relativism, but the threats to realism are real and require much discussion, which I expect to provide in another place. These problems have already emerged repeatedly in this paper: in transitions between object language and metalanguage, for example, or in constant substitution of talk about how the world used to be, for talk about how people thought it was. They will emerge again below in my implied refusal to suppose, with Putnam, that the need to make drastic changes in the set of objects to which a term once referred indicates that it did not, in fact, refer at all.

22. Views that, like mine, depend on talking about the way words are actually used, the situations in which they apply, are regularly charged with invoking a "verification theory of meaning," not currently a respectable thing to do. But in my case at least that charge does not hold. Verification theories attribute meanings to individual sentences and through them to the individual terms those sentences contain. Each term has a meaning determined by the way in which sentences containing it are verified. I have been suggesting, however, that with occasional exceptions terms do not *individually* have meanings at all. More important, the view sketched above insists that people may use the same lexicon, refer to the same items with it, and yet pick out those items in different ways. Reference is a function of the shared structure of the lexicon, but not of the varied feature spaces within which individuals represent that structure. There is, however, a second charge, closely related to verificationism, of which I am guilty. Those who maintain the independence of reference and meaning also maintain that metaphysics is independent of epistemology. No view like mine (in the respects presently at issue there are a number) is compatible with so stringent a separation. The distinction between metaphysics and epistemology can be drawn only from within a position that involves both.

23. "The Meaning of Meaning," in *Mind, Language and Reality* (Cambridge: Cambridge University Press, 1975), 215–71, especially 223ff. All the quotations that follow are from the latter pages. Putnam has, I believe, now abandoned significant components of the essentialist viewpoint that underlies this paper, moving from it to a view ("internal realism") with significant parallels to my own. But

few philosophers have followed him: both the examples and the viewpoint discussed below are still very much alive.

24. *Naming and Necessity* (Cambridge: Harvard University Press, 1980), 118.

25. The force of Putnam's discussion depends in part upon an equivocation that needs to be eliminated. As used in everyday life or by the laity, 'water' has through history behaved much like 'gold'. But that is not the case within the community of scientists and philosophers to which Putnam's argument needs to be applied.

26. Laypeople can, of course, say that water is H_2O without controlling the fuller lexicon or the theory that it supports. But their ability to communicate by doing so depends upon the presence of experts in their society. The laity must be able to identify the experts and say something of the nature of the relevant expertise. And the experts must, in turn, command the lexicon, the theory, and the computations.

27. At issue, of course, is where to draw the boundary lines that delimit the referents of 'water', 'living thing', and so on, a problem that arises from and seems to threaten the notion of natural kinds. That notion is closely modeled on the concept of a biological species, and discussions of causal theory repeatedly invoke the relation between a particular gene type and a corresponding species (often tigers) to illustrate the relation said to hold between a natural kind and its essence between H_2O and water, for example, or between atomic number 79 and gold. But even individuals who are unproblematically members of the same species have differently constituted sets of genes. Which sets are compatible with membership in that species is a subject of continuing debate, both in principle and practice, and the subject of the argument is always which superficial *properties* (e.g., the ability to interbreed) the members of a species must share.

28. Even for gold this generalization is not *altogether* correct. As mentioned above, scientific progress does result in marginal adjustments of the original samples of gold by virtue of "our increased ability to detect impurities" (see n. 23). But what it is for gold to be pure is determined in part by theory. If gold is the substance with atomic number 79, then even a single atom with a different atomic number constitutes an impurity. But if gold is, as it was in antiquity, a metal that ripens naturally in the earth, changing gradually from lead through iron and silver to gold in the process, then there is no single form of matter that is gold *tout court*. When the ancients applied the term "gold" to samples from which we might withhold it, they were not always simply mistaken.